Research Initiatives in Recycling and Substitutes of Rare Earth Elements

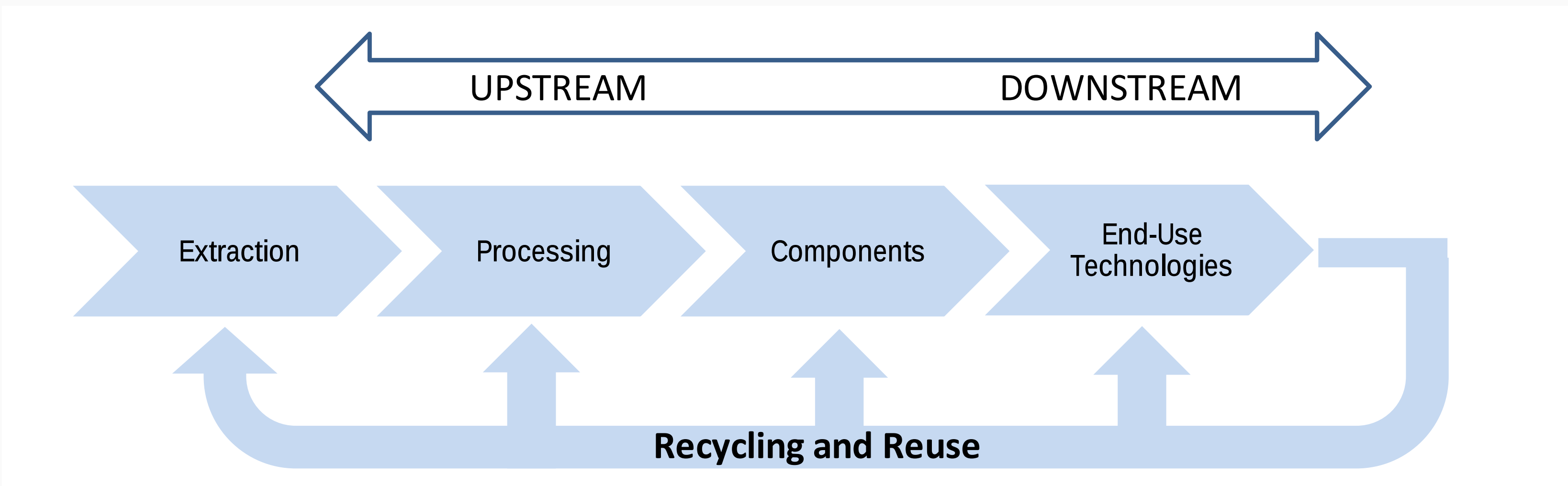
Dr. Michael McKittrick
U.S. Environmental Protection Agency
Office of Research and Development

Disclaimer

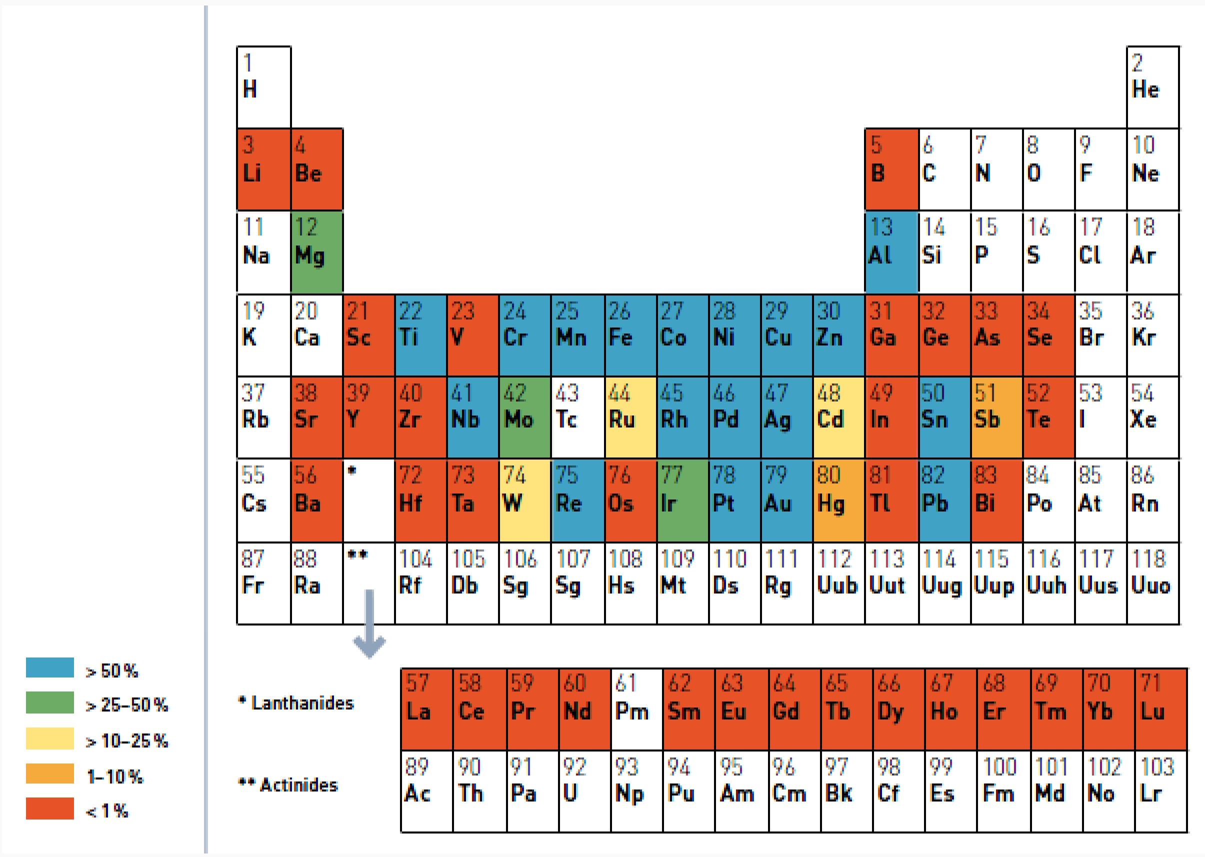
- The perspectives, information and conclusions conveyed in this presentation convey the viewpoints of the presenter and may not represent the views and policies of ORD and EPA

- Recycling and Reuse
  - Challenges
  - Opportunities
  - EPA SBIR
- Substitutions
- Federal Government Efforts
  - Office of Science and Technology Policy (OSTP)
  - DOE Critical Materials Strategy

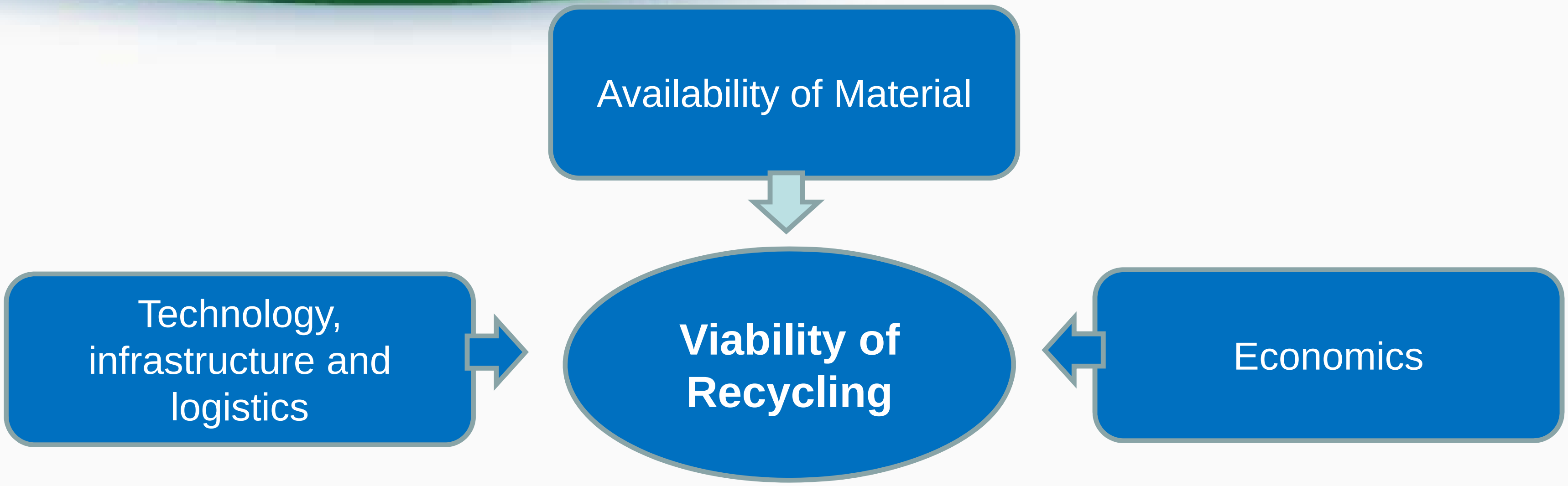
Recycling and Reuse



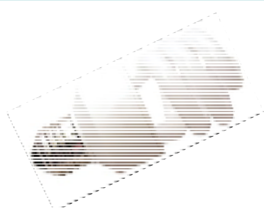
EOL Recycling Rates



Recycling Rates of Metals - United Nations Environmental Programme, 2011



Opportunities

End of Product Life Recycling		30% of fluorescent bulbs are already recycled for mercury removal, but phosphors end up in landfills
Reducing/Reusing Manufacturing Loss		30% loss of magnetic material during machining, but could be reduced

DOE Critical Materials Strategy, 2011

Potential of Recycling Consumer Electronics

- NdFeB magnets
  - 30% Nd by weight
  - Desktop HDDs
    - ~13 g magnet/drive
    - 23 million sold in US in 2010
  - Laptop HDDs
    - ~6 g magnet/drive
    - 40 million sold in US in 2010

Challenges/Opportunities

- Removal of HD from computer
- Adhesives and nickel plating on magnets
- Magnetization
- Purity
- ***Lack of processing capability***
- ***Need for improved Product Design***
- ***EH&S issues***

EPA Small Business Innovation Research (SBIR) Program

Electron Energy Corporation

- Recovering REEs from manufacturing swarf
- Recycling magnets from consumer electronics

OnTo Technology

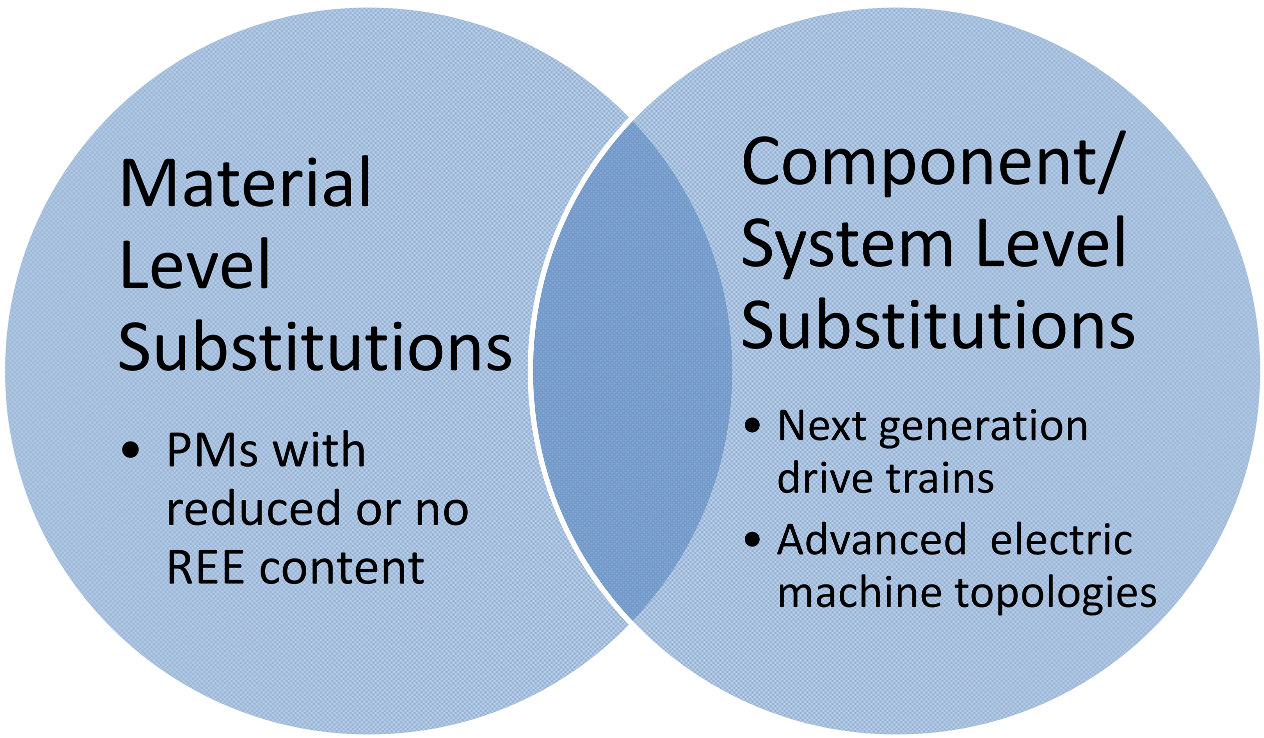
- Developing process to recover REEs from NiMH batteries
- Potential application to Li-ion technology

EPA SBIR Phase I awards: $80K – 6 months
FY13 solicitation now open
Topics of interest include: More efficient and effective separation techniques, recycling technologies and technologies to facilitate collection

Substitutes

Substitutes for Rare Earth Permanent Magnets for Motors and Wind Generators

FY 2011 R&D Investments		
ARPA-E REACT	EERE Vehicle Technologies Program	EERE Wind Program
$30 million	$6 million	$7.5 million



Novel High-Energy Permanent Magnets without Critical Elements

PI: R. William McCallum, Ames Laboratory, Ames, IA

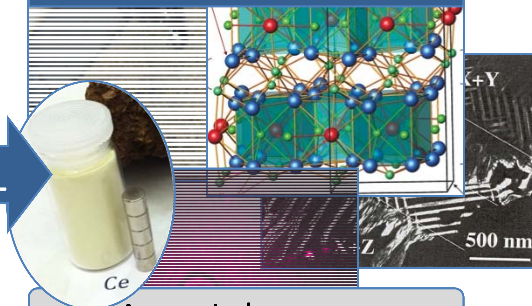
50% of oxide in ore is Ce

Molycorp Minerals

Stan Trout

1

Designer Ce-TM Magnet

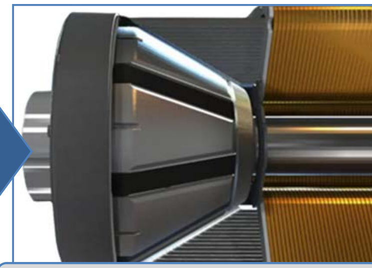


Ames Laboratory

R. W. McCallum, D. Johnson, V. Antropov, K. Gschneidner, M. Kramer, V. Pecharsky

2

Larger-Field Motor via Magnet Shape Design



NovaTorque

John Petro

3

Usable Drive Motors

General Motors

Fred Pinkerton

Molycorp Bastnasite
4x (12x) more Ce than Nd (Pr)
=> 4x more Ce-based magnets than Nd-Pr-based magnets

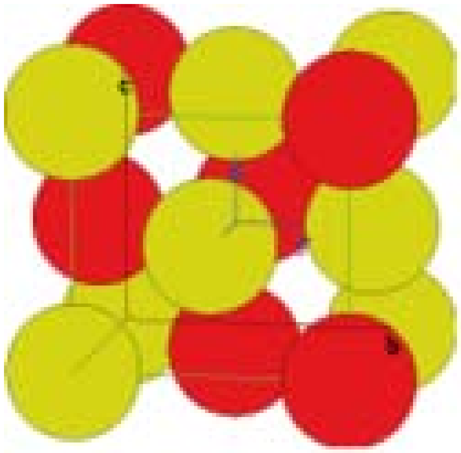
Key Milestones & Deliverables
• Jointly characterize Ce-TM *baseline* alloys • Develop/assess Ce-(Fe,TM)-X alloys (X=H,N).
• Evaluate and down-select interstitially and/or substitutionally modified Ce-TM magnets

Suitable Ce-based magnets are undeveloped. *Via integrated computational engineering and advanced synthesis and processing, **Ames Laboratory will***:

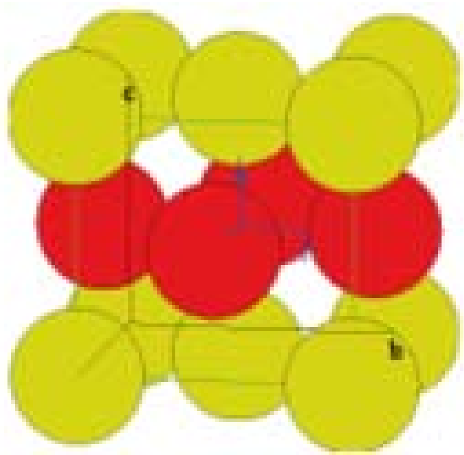
Control and manipulate the intrinsic and extrinsic magnetic properties of **Ce-Transition-Metal permanent magnets <u>for automotive traction motors</u>**.

Develop a Ce-TM based magnet for motors having Tc > 300 C, a remnant magnetization >1 Tesla, and a coercivity >10 KOe, needed for technology.

Courtesy of arpa·e

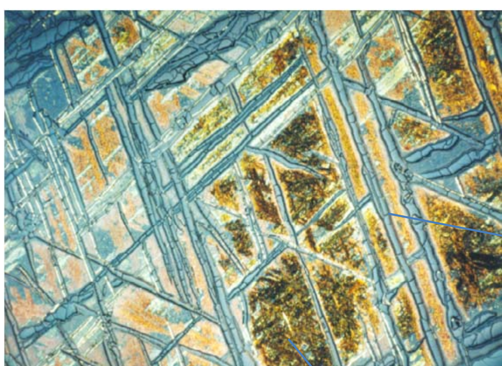


Disordered



Ordered

(From http://www.neel.cnrs.fr/spip.php?article1083&lang=en)



Ordered

Disordered

J.I. Goldstein, *et al*., Chemie der Erde - Geochemistry, Volume 69, Issue 4, November 2009, Pages 293-325.

- $L1_0$ FeNi phase in large numbers of stony, stony-iron and iron **meteorites**.
- Typical cooling rates: **0.2 K/Myr to 2,000 K/Myr** for chemical ordering at the low temperatures (<300 ºC) where the desired phase forms.
- Ordered structures are magnetic -BH_{max} = 40 MGOe (NdFeB- BH_{max} = 59 MGOe)

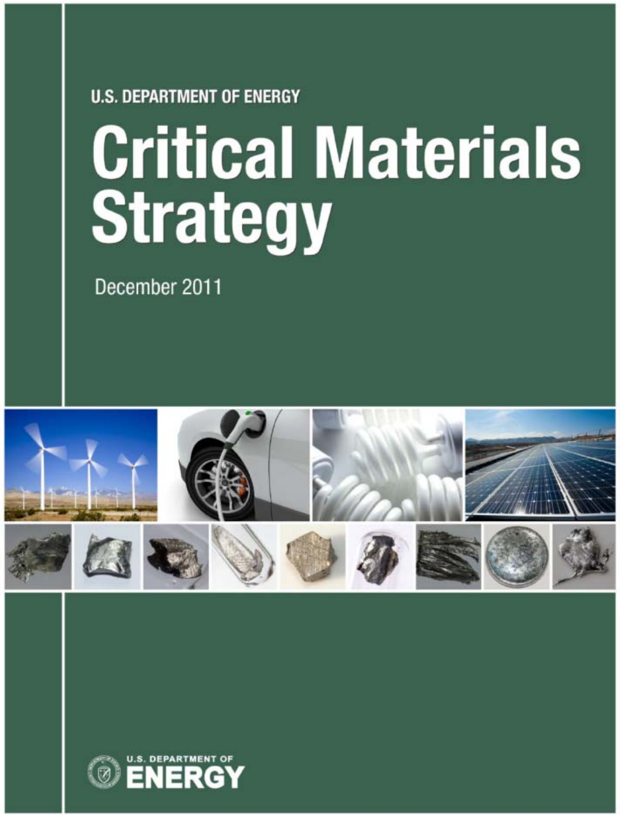
Courtesy of arpa·e

Office of Science and Technology Policy (OSTP) convened four work groups:

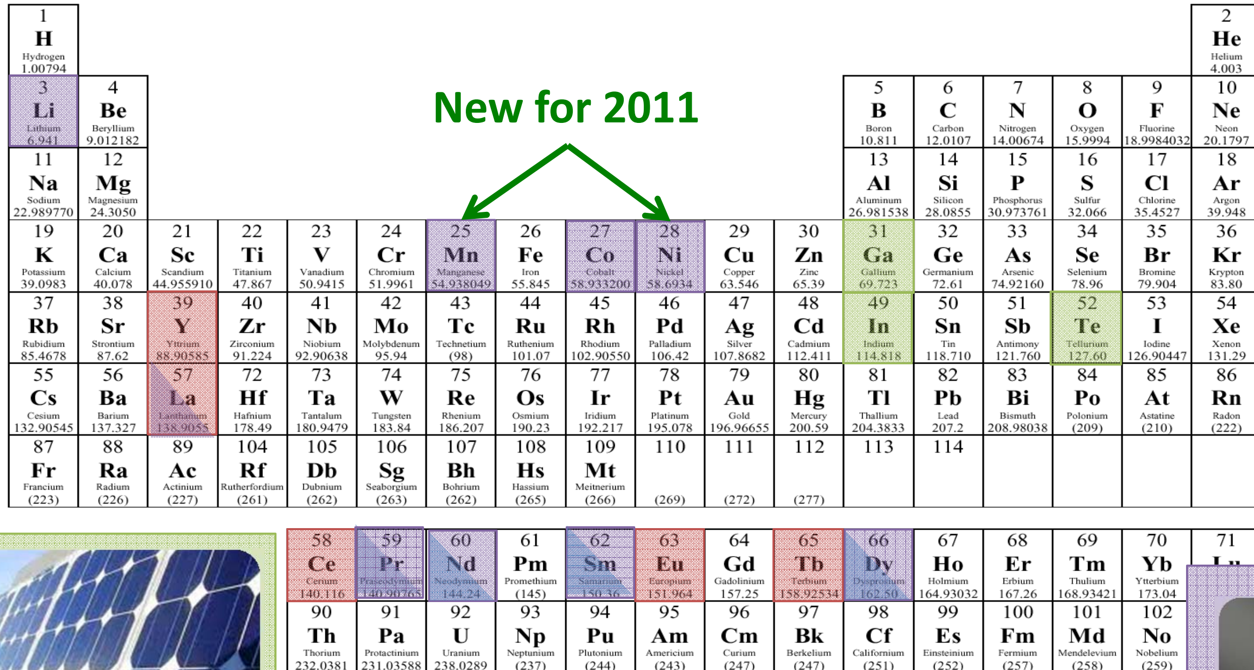
- Critical Material Criteria and Prioritization
- Federal R&D Prioritization
- Globalization of Supply Chains
- Depth and Transparency of Information

2011 Critical Materials Strategy:

- Provides an updated criticality analysis
- Sets forth several case studies, including oil refining catalysts
- Discusses critical materials market dynamics
- Presents DOE's Critical Materials R&D Plan



2011 DOE Critical Material Strategy Scope



Vehicles

Lighting

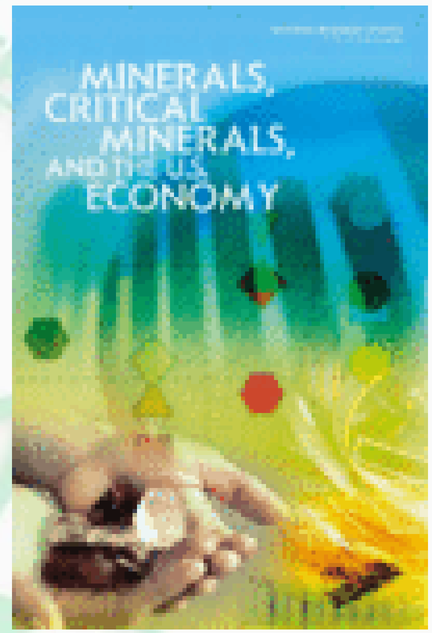
Solar PV

Wind

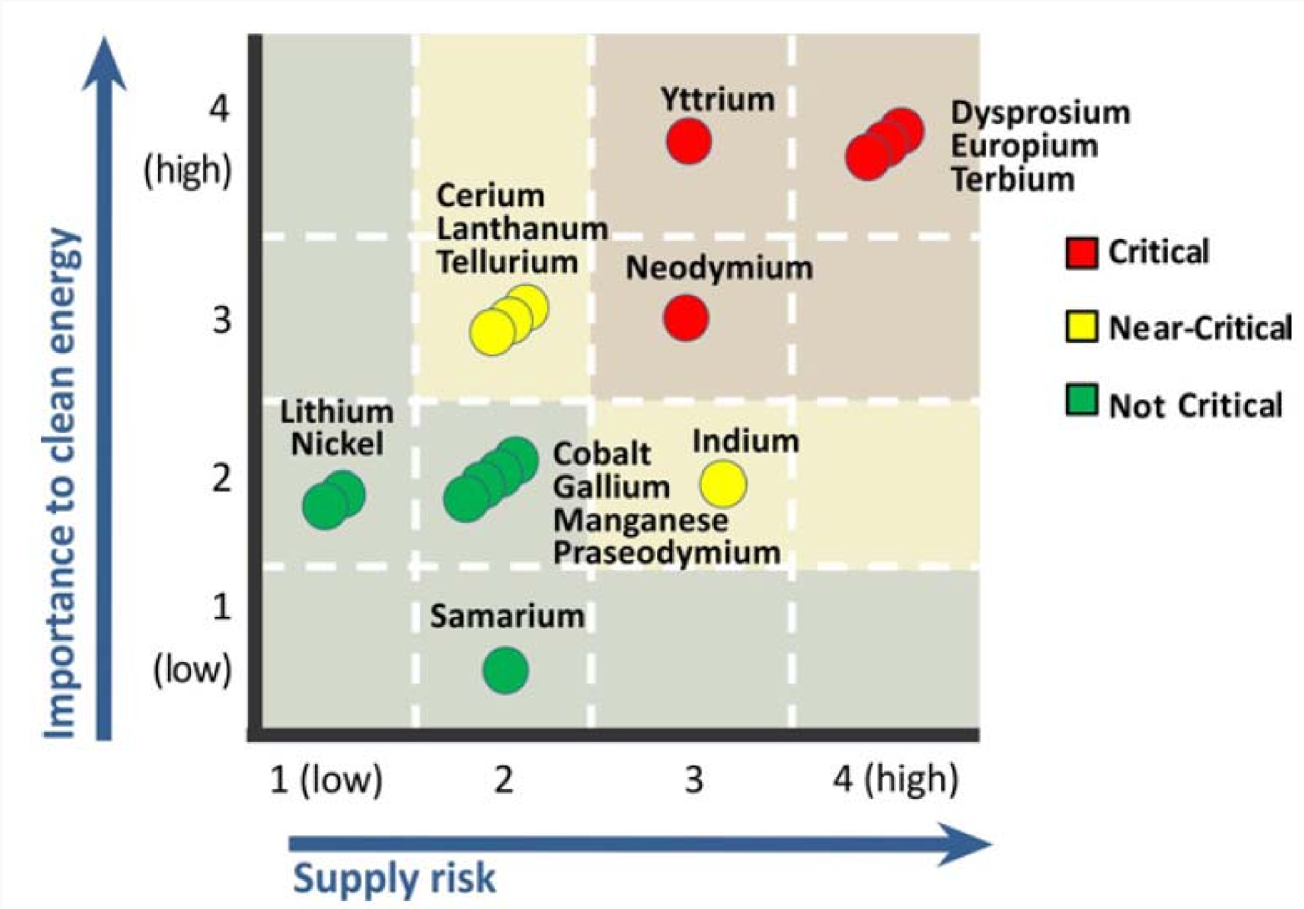
DOE’s 2011 Critical Materials Strategy

Criticality Assessments

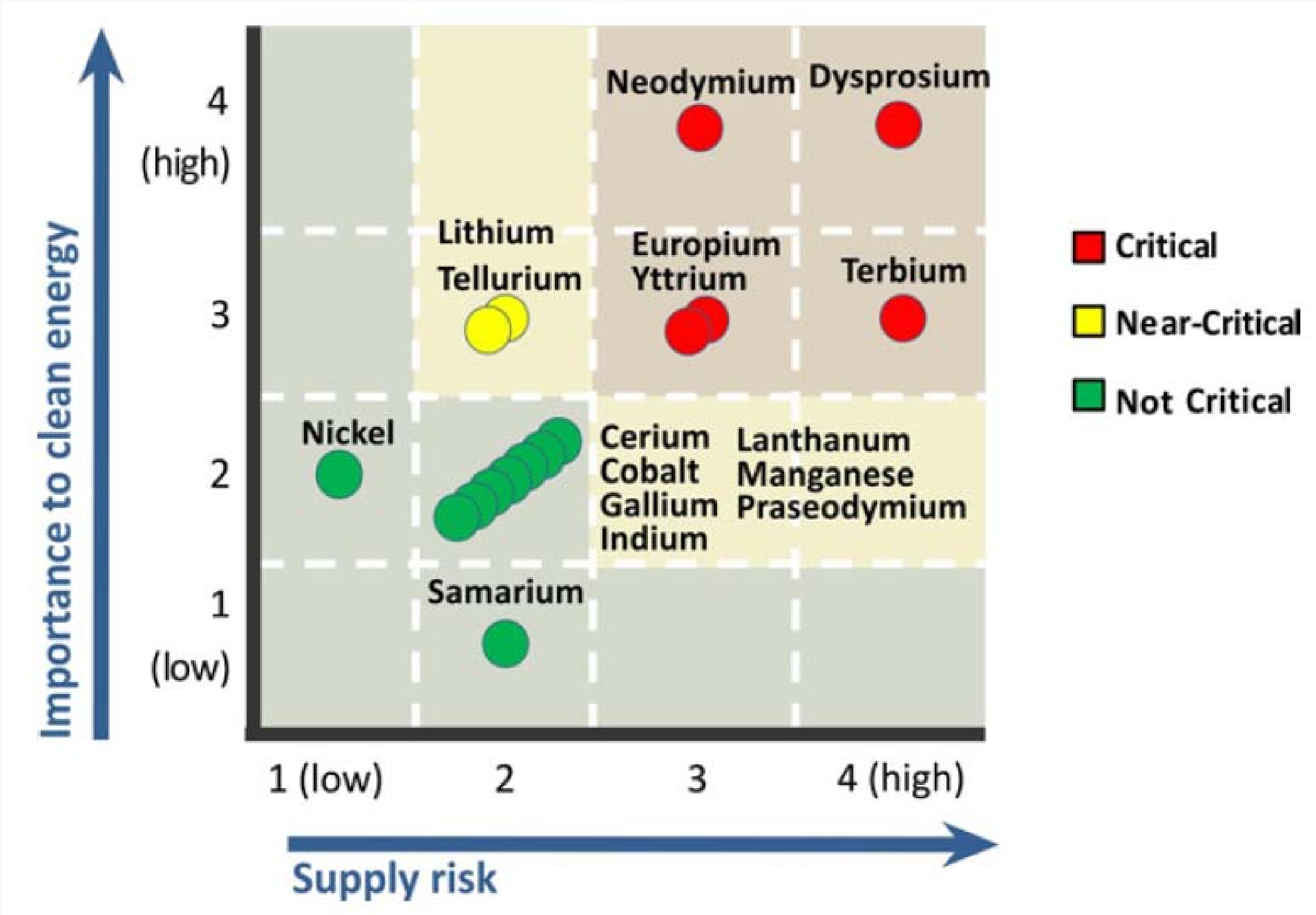
- Methodology adapted from National Academy of Sciences
- *Criticality* is a measure that combines
    - Importance to clean energy technologies
        - Clean Energy Demand; Substitutability Limitations
    - Risk of supply disruption
        - Basic Availability; Competing Technology Demand; Political, Regulatory and Social Factors; Co-Dependence on Other Markets; Producer Diversity
- Time frames:
    - Short-term (Present - 2015)
    - Medium-term (2015 - 2025)



2011 CMS Short-Term Criticality (Present - 2015)

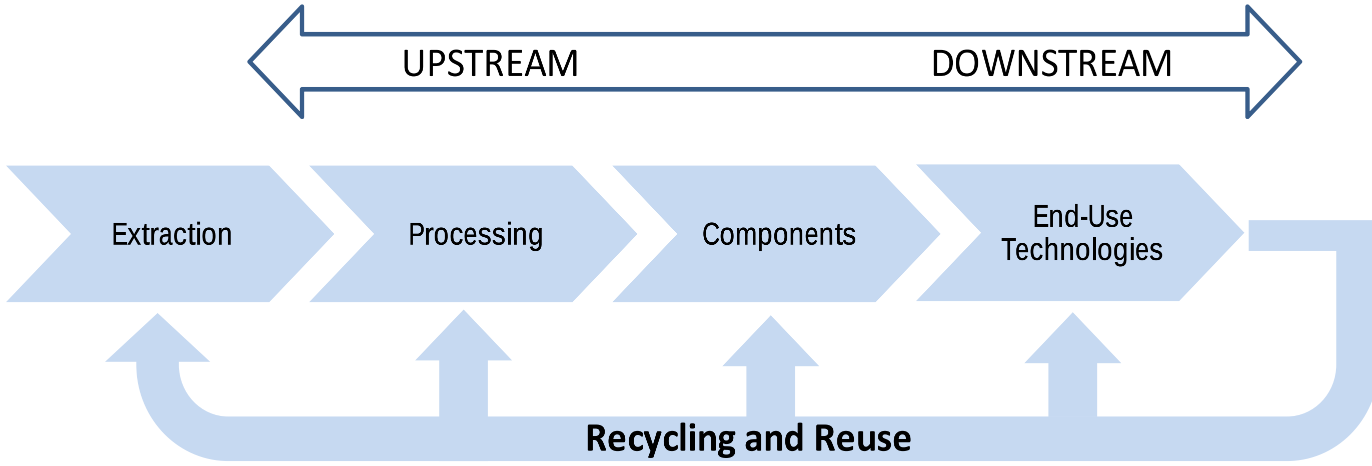


2011 CMS Medium-Term Criticality (2015-2025)



Strategic Pillars

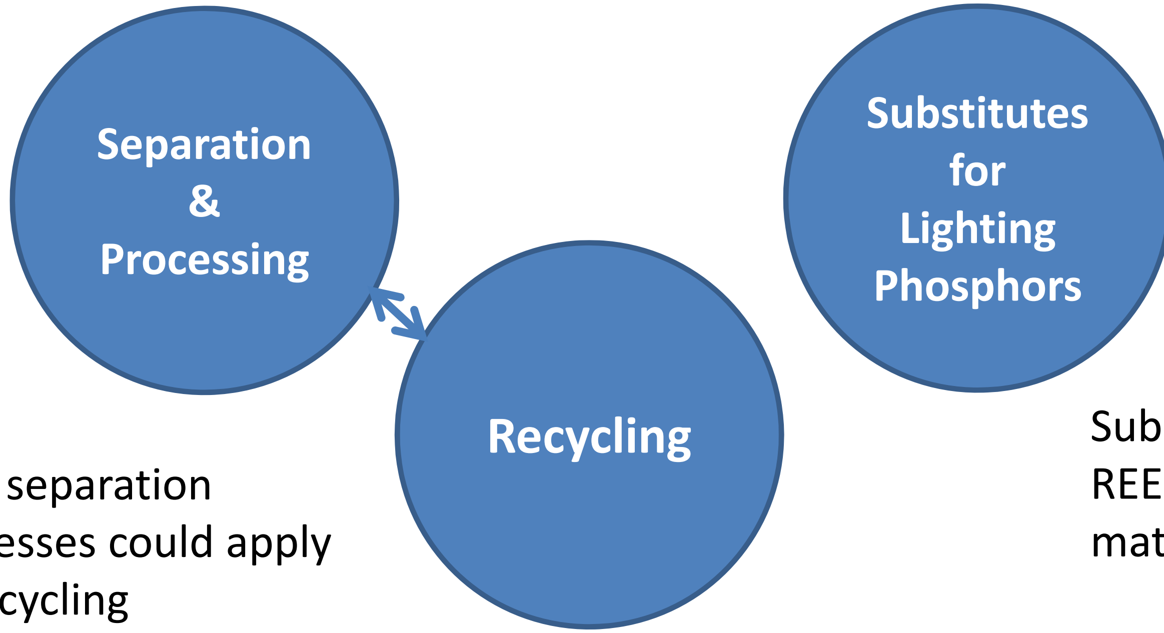
- *Diversify global supply chains*
- *Develop substitutes*
- *Reduce, reuse and recycle*



Material supply chain with environmentally-sound processes

Next R&D Challenges and Opportunities

Efficient & environmentally friendly processes



New separation processes could apply to recycling

Substitute critical REEs with abundant materials

Related DOE R&D Initiatives

- Critical Materials Energy Innovation Hub –identifying more efficient use of critical materials in energy technologies and improving the efficiency, and reducing the production costs, for supplies of critical materials – April 3rd workshop
- Innovative Manufacturing Initiative – transformational manufacturing process and materials technologies
- Small Business Innovation Research (FY12 FOA)– lanthanide separation & processing topics

DOE's 2011 Critical Materials Strategy - Main Messages

1. Critical supply challenges for five rare earths (dysprosium, neodymium, terbium, europium, yttrium) may affect energy technologies in years ahead
2. In past year, DOE and other stakeholders have scaled up work to address these challenges
3. Building workforce capabilities through education and training will help realize opportunities
4. Much more work required in years ahead

Summary

- Recycling
  - Opportunities available to take advantage of recycling potential
  - Need for R&D to facilitate these opportunities
- Substitutes for REEs
  - DOE has supported a wide variety of programs to reduce dependence on REEs for green energy applications
  - Most work underway is early stage research
- Federal Efforts
  - Many agencies are engaged on issues related to REEs
  - Interagency efforts are being coordinated through OSTP

Contact Information

Mike McKittrick
U.S. EPA
Office of Research and Development
National Center for Environmental Research
703-347-8100
mckittrick.michael@epa.gov

Separation & Processing

- Solvent Extraction
  - REEs are very chemically similar which makes them difficult to separate
  - Very small separation factors
  - Hundreds of solvent extraction stages
  - Up to 1 year to process ore

Potential Advances

- New Molycorp Facility
  - Combines chlor-alkali process with REE separation
  - Recycles 90% of wastewater
  - Eliminates 120 acres of evaporation ponds
  - Recycle reagents
  - More cost effective

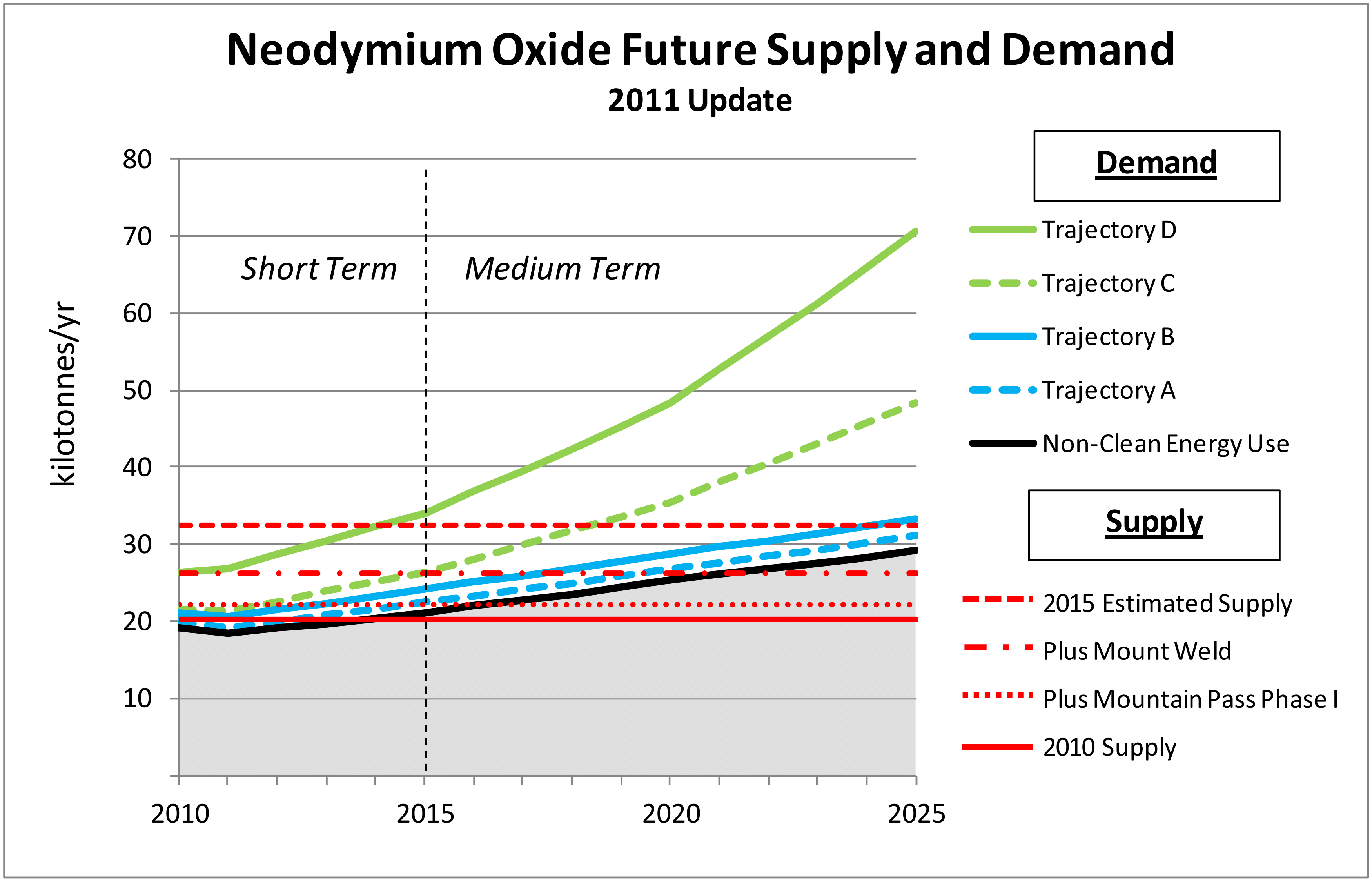
- Other routes
  - Supercritical Fluid extraction
  - Biologically inspired approaches
  - Electrochemistry
  - Ionic liquids
  - Selective Extraction

Material Demand Factors

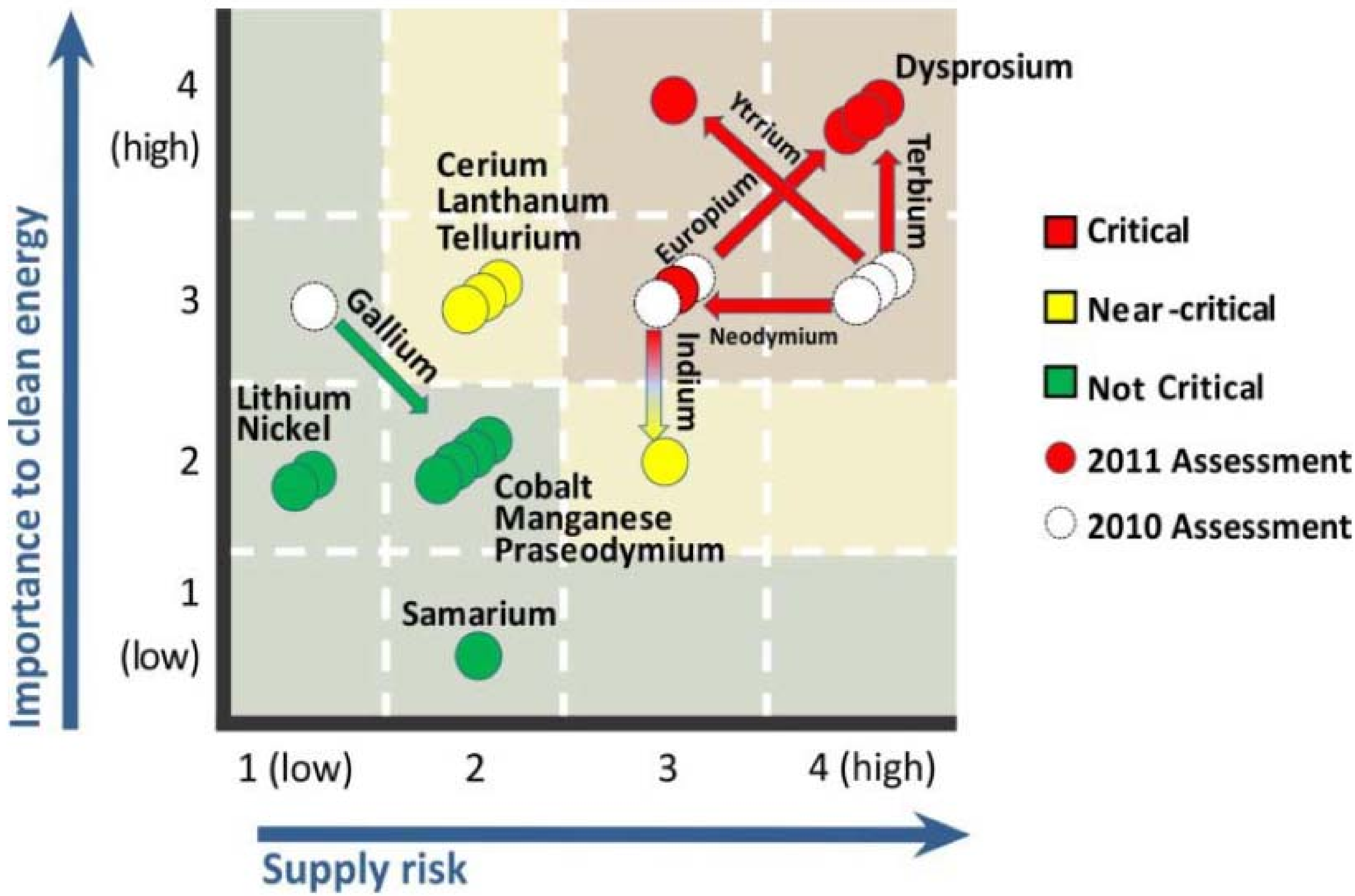
	Market Penetration	Material Intensity
Trajectory D	High	High
Trajectory C	High	Low
Trajectory B	Low	High
Trajectory A	Low	Low

- ***Market Penetration = Deployment*** (total annual units of a clean energy technology) ***X Market Share*** (% of units using materials analyzed)
- ***Material Intensity =*** Material demand per unit of the clean energy technology

Neodymium - Supply and Demand Projections
Critical Materials Strategy 2011



Short-Term Comparison between 2010 CMS and 2011 CMS



Medium-Term Comparison Between 2010 CMS and 2011 CMS